Chapter 8
Journey Inside the Atom

Redeveloped Edition *| Class 9 Science | IESC Series*

Original NCERT content reimagined with everyday Indian-life examples, redeveloped worked problems, and interdisciplinary insight — same rigour, re-anchored in 2026.

Opening Wonder

Diwali night. The terrace is full of smoke and noise, and every few seconds the sky answers back — a shower of gold, a burst of blue-green, a streak of blood red, a flash of pure white. Your little cousin is convinced the colours come from some kind of paint mixed into the firecracker. You're not so sure, but you can't explain it either. Why gold from one anaar (ground spinner) and green from another, when both are just "chemicals wrapped in paper"?

Here's the surprising truth: **those colours are the fingerprints of individual atoms.** Sodium compounds burn golden-yellow, barium burns green, strontium burns red, copper burns blue — every element lights up in its own signature colour when it's heated enough, because of something happening deep inside each atom, far smaller than anything a sparkler could ever show you directly. By the end of this chapter, you'll know exactly what that something is.

Now look around the rest of your world. The phone in your pocket, the concrete pillar holding up your balcony, the rice on your dinner plate, and you yourself — skin, blood, bone — are all, at the deepest level, built from the same basic kit of parts. Picture a house: it is made of walls, which are made of bricks, which (if you could zoom in far enough) are made of silicate compounds, which are made of atoms of silicon, oxygen, and a handful of other elements. Now picture your own body: made of organs, made of tissues, made of cells, made of proteins, made of atoms of carbon, hydrogen, oxygen, nitrogen, and phosphorus. A house and a human being could not look more different — yet both stories end at exactly the same place: **atoms.**

These atoms are so tiny that no microscope you've ever looked through could show you one directly — you'd need roughly ten million of them lined up, edge to edge, just to stretch across the full stop at the end of this sentence. And yet everything solid, liquid, and gaseous that you have ever touched, tasted, or breathed is built entirely out of them.

This raises a question that has bothered thoughtful people for well over two thousand years, in India and far beyond it: **if you kept dividing a grain of rice, or a drop of water, or a strip of aluminium foil, into smaller and smaller pieces, would you eventually reach a piece that simply could not be divided any further?** And if atoms really are that smallest piece — solid, indivisible, final — then why do electrons, which are attracted to the positively charged centre of an atom the way a ball is attracted to the ground, not simply come crashing in? Why did scientists keep discarding one careful, evidence-based model of the atom and replacing it with another, again and again, across more than a century? This chapter is the story of how that question was asked, tested, overturned, and asked again — the actual, unfinished journey inside the atom.

> **Think It Over — Before You Begin**

- Are atoms really the smallest, indivisible particles of matter — or can they be broken down further?
- Electrons are pulled toward the positively charged part of the atom. So why don't they simply spiral in and collide with it?
- Why did scientists keep changing their model of the atom instead of settling on one and moving on?

8.1 Rediscovering the Roots of Atomic Theory

Long before anyone had a microscope, a battery, or a vacuum pump, thinkers in two very different civilisations arrived — independently — at strikingly similar ideas about matter. In ancient India, the sage **Acharya Kanada** (traditionally placed somewhere between the 6th century BCE and the early centuries CE) proposed that if you divided *dravya* (matter) again and again, you would eventually reach a stage where the resulting particles could not be divided any further. He called these ultimate particles *__parmanus__*. *His ideas survive in the Sanskrit text known as the* **Vaisesika Sutras***. According to Kanada, a parmanu is infinitely small and beyond the reach of the senses; parmanus combine in pairs (dyads) and triads to build up the entire material universe, living bodies included — though the text does not specify exactly what proportions of parmanus combine to form which substances.

Around the same broad era, the Greek philosophers **Leucippus** and **Democritus** proposed something remarkably close: indivisible particles they called *__atomos__* — Greek for "uncuttable." Neither the Indian nor the Greek idea came from a laboratory experiment. Both were philosophical reasoning — brilliant guesses about the structure of reality, not measurements of it.

It took until **1808** for the idea to become a genuine scientific theory. English chemist **John Dalton** proposed that all matter is made of indivisible particles called atoms — the fundamental building blocks of matter that cannot be broken down further — and, crucially, he backed this up with quantitative experiments on how substances combine in fixed proportions. Dalton's atomic theory was the first scientific description of matter's structure, and it remains the starting point for everything you're about to learn.

Everyday Connection: Zooming In Until You Hit the Pixel

Open any photo on your phone and keep pinching to zoom in. For a while, the image just gets bigger and clearer. But past a certain point, it stops looking like a photo at all — you're staring at a grid of solid-coloured little squares, the **pixels**, which cannot be zoomed into any further without the image simply looking blocky and broken. Ancient thinkers reasoned about matter the same way Kanada reasoned about *dravya*: keep dividing, and eventually you hit a floor. A pixel isn't really a perfect analogy for an atom — atoms are physical particles, not display units, and (as you'll see in this very chapter) atoms turned out to be divisible after all. But the *reasoning style* — dividing repeatedly until you can't divide any further — is exactly the logical move both Kanada and Democritus made, two thousand years before anyone could test it directly.

Meet a Thinker: Acharya Kanada

Acharya Kanada was an ancient Indian sage and the founder of the Vaisesika school of Indian philosophy. Scholars are not certain exactly when he lived — estimates range from roughly the 6th century BCE to the early centuries of the Common Era — but his central idea, recorded in the *__Vaisesika Sutras__*, was strikingly modern in spirit: matter divided repeatedly reaches an indivisible limit, the* parmanu*. He reasoned his way to this idea through logic and observation of the natural world, without any laboratory instruments — a reminder that some of the deepest scientific questions were first asked as philosophy.

Meet a Scientist: John Dalton (1766–1844)

John Dalton was an English chemist and schoolteacher from a Quaker family. In 1808, in his book *__A New System of Chemical Philosophy__*, he proposed the first evidence-based atomic theory, building it on careful experimental measurements of how elements combine in fixed proportions to form compounds. Dalton was also colour-blind, and his detailed studies of his own condition were so influential that colour blindness is still sometimes called Daltonism*. In 1803, he additionally introduced some of the first pictorial symbols for chemical elements — an idea you'll meet again in section 8.4.

Dalton's theory raised as many questions as it answered. If atoms are the fundamental building blocks, what are *they* made up of? What would an atom look like, if you somehow could see one? And what makes the atoms of one element — say, gold — different from the atoms of another, say, oxygen? Answering these questions took more than a century of careful, and sometimes accidental, experimentation.

8.2 A Short Historical Journey Through Atomic Models

For most of the 19th century, atoms were assumed to be exactly what Dalton had proposed — solid, indivisible, final. Then, late in the century, scientists discovered that certain elements spontaneously emit invisible energy and particles, a phenomenon called **radioactivity**. If atoms could throw off pieces of themselves, they clearly weren't indivisible after all. Something had to be inside them — and the race to find out what began.

8.2.1 Thomson's model of an atom

In 1897, **J. J. Thomson** was studying how electric current passes through gases at very low pressure. Using a glass tube fitted with two electrodes and a high voltage supply, he observed a stream of rays travelling from the cathode (negative electrode) to the anode (positive electrode) — these came to be called **cathode rays**. By deflecting these rays with electric and magnetic fields, Thomson showed they were streams of negatively charged particles, far lighter than any atom. These particles were later named **electrons**. Because the cathode rays behaved identically no matter which metal the cathode was made of, or which gas filled the tube, Thomson concluded that electrons must be a fundamental component of every atom of every element. By convention, the electron's charge (-1.602×10^{-19} C) is simply taken as **-1**.

This left Thomson with a puzzle: atoms, overall, are electrically neutral, so where was the positive charge that must be balancing all these negative electrons? He proposed that an atom is a sphere of positive charge with electrons scattered through it like currants in a pudding — which is exactly why this became known as the **plum pudding model**. A more familiar Indian picture: think of a **watermelon**, where the red pulp is the positively charged matter and the black seeds scattered through it are the

electrons. It was the first genuine attempt to explain how an atom's positive and negative charge could coexist in balance — even though, as you're about to see, it turned out to be wrong.

Everyday Connection: You're Watching Thomson's Discovery's Great-Grandchild

If your grandparents describe watching cricket on a bulky box-shaped television with a curved glass screen, they were watching a **cathode ray tube (CRT) television** — a direct technological descendant of the very tube Thomson used to discover the electron. A beam of electrons, fired from the back of the tube, was steered by magnetic fields to strike a phosphor-coated screen and paint the picture, line by line, thirty times a second. Flat-panel LED and OLED screens have replaced CRTs almost everywhere in India now, but the electron itself — first identified in exactly this kind of apparatus — is still doing the work inside every modern chip, wire, and battery you own.

Meet a Scientist: J. J. Thomson (1856–1940)

J. J. Thomson's most significant discovery was the electron — the first subatomic particle ever identified, and a component of every atom. He was awarded the **1906 Nobel Prize in Physics** for his research into the electrical conductivity of gases, the very research that led him to the electron. As head of the famous Cavendish Laboratory at the University of Cambridge, Thomson went on to guide and inspire a generation of scientists — including Ernest Rutherford, whose experiment would soon overturn Thomson's own atomic model.

Activity — Redeveloped: Build Thomson's Atom in Your Kitchen

Original book version: Imagine your own "atom" as Thomson described it, using clay for the positive charge and small beads for the electrons spread through it. What happens if the positive charge on the clay is less than the total negative charge of the beads? What if the clay itself accidentally carries a bit of negative charge — would your model still represent a neutral atom?

Everyday Version: Instead of clay and beads, use a ball of **laddoo dough (besan or atta)** as the positively charged sphere, and press in a scatter of **til (sesame) seeds** as the electrons. Work through the same two questions with your edible model: (i) What does it mean, physically, if you press in more sesame seeds than the "positive charge" of the dough can balance? (ii) If the dough itself secretly carried some negative charge (say, from a contaminated batch), would sesame-seeds-in-dough still add up to a neutral laddoo?

Bonus: Could an orange or a mosambi (sweet lime), with its pulp and seeds, work just as well as a stand-in for Thomson's model? Where does the comparison hold up, and where does it break down — for instance, are the "seeds" of a fruit actually spread evenly through the pulp the way Thomson imagined electrons to be?

8.2.2 Testing Thomson's model: the gold foil experiment

In 1911, **Hans Geiger** and **Ernest Marsden**, working under Ernest Rutherford, put Thomson's model to the test in what became one of the most famous experiments in the history of science: the **gold foil experiment**. They fired a narrow beam of **alpha particles** — tiny, positively charged particles emitted by certain radioactive elements (you'll later learn an alpha particle is simply the nucleus of a helium atom: two protons and two neutrons) — at an extremely thin sheet of gold foil.

If Thomson's model were correct, the positive charge inside each gold atom would be spread out evenly, like charge smeared through a pudding, and the alpha particles should sail through with at most a gentle wobble. That is indeed what happened to most of them. But to everyone's astonishment, a small number of alpha particles were deflected through large angles — and a handful bounced almost straight back the way they came. This sideways-and-backward deflection is called **scattering**, which is why the experiment is also known as the **α-particle scattering experiment**. Thomson's plum pudding model had no way to explain it: a sphere of evenly spread positive charge simply isn't dense or concentrated enough anywhere to fling a fast, heavy alpha particle backward.

Everyday Connection: The Metro Security Scanner Works on the Same Logic

Walk into almost any Indian metro station, airport, or stadium today and your bag passes through an X-ray scanner. Most of the X-rays sail straight through the soft fabric and paper inside your bag — but a dense metal object (a laptop battery, a pair of scissors, a phone) blocks or scatters the rays sharply, which is exactly what shows up as a bright, hard-edged silhouette on the operator's screen. Rutherford's team read the gold foil experiment the same way: most alpha particles passing straight through told them the atom is mostly empty space, while the rare sharp deflections told them something small, dense, and heavily charged must be hiding inside — the **nucleus**. In both cases, what *doesn't* scatter is just as informative as what does.

A. Rutherford's model of an atom

From these results, Rutherford concluded that the positive charge of an atom is not spread throughout its volume but is concentrated in an extremely small region at the centre — the **nucleus**. He proposed that:

- Most of an atom is empty space, since most alpha particles passed straight through the gold foil undeflected.
- The nucleus is dense, and contains all of the atom's positive charge along with almost all of its mass.
- Electrons revolve around this nucleus, somewhat like planets orbiting the Sun — earning this the name the **planetary model** of the atom.

Rutherford calculated just how small the nucleus really is: about one lakh (10^5) times smaller than the atom itself. The diameter of a typical atom is roughly 10^{-10} m, while the diameter of its nucleus is only about 10^{-15} m. To get a feel for that ratio: if an atom were blown up to the size of a full cricket ground (about 100 m across), its nucleus would be a single grain of black pepper sitting at the centre of the pitch.

Ready to Go Beyond: A Sheet of Paper Is a Million Atoms Thick

How many atoms would it take, stacked one on top of another, to make a sheet of paper 0.1 mm thick — about as thick as a page in this book (or, just as easily, a single strand of human hair, which is also roughly 0.1 mm across)?

If one atom is about 10^{-10} m across, and the sheet (or the hair) is 0.1 mm = 10^{-4} m thick, then:

number of atoms ≈ (10^{-4} m) ÷ (10^{-10} m) = **10^6**, i.e. about **one million atoms**, stacked edge to edge.

The next time you run a finger down a strand of hair or flip a page of this textbook, remember: you're touching roughly a million atoms lined up shoulder to shoulder,

all invisibly holding hands to make something you can actually feel.

Meet a Scientist: Ernest Rutherford (1871–1937)

Born in New Zealand, Ernest Rutherford moved to Cambridge to work with J. J. Thomson and went on to become known as the **Father of Nuclear Physics**. He discovered the atomic nucleus and explained how certain elements naturally break down radioactively, work for which he won the **1908 Nobel Prize in Chemistry** — a physicist honoured with a chemistry prize. In 1911 he proposed the nuclear model of the atom described above. His portrait now appears on New Zealand's $100 banknote.

B. Limitations of Rutherford's model

Rutherford's nuclear model explained the gold foil results far better than Thomson's ever could — but it had a serious flaw: it could not explain why atoms are **stable**. A charged particle moving in a circular path is constantly changing direction, which means it is continuously accelerating. An accelerating charged particle is expected to radiate energy away. If an electron circling the nucleus kept losing energy this way, it should spiral inward and eventually crash into the nucleus — and the atom should collapse. In reality, of course, atoms don't collapse; the matter around you stays exactly as solid as it was yesterday. This meant Rutherford's model, however useful, was not the full story.

But before addressing that gap, scientists needed to understand another subatomic particle already hiding inside the nucleus — the one responsible for the nucleus's positive charge in the first place: the **proton**, discovered and named by Rutherford himself.

C. Discovery of the proton

Rutherford showed that the positive charge of the nucleus comes from particles called **protons**, which are much heavier than electrons and carry a charge equal in size, but opposite in sign, to the electron's. Because an atom as a whole is electrically neutral, the number of protons in it must always equal the number of electrons. A helium atom, for instance, has 2 protons and 2 electrons; a sodium atom has 11 of each. Since the total positive charge always exactly balances the total negative charge, every atom of every element is electrically neutral overall.

8.2.3 Bohr's model of the atom

To resolve the stability problem, Danish physicist **Niels Bohr** proposed a new model of the atom in 1913. Bohr suggested that electrons do not move about randomly, but instead follow fixed circular paths called **stationary states**, **orbits**, or **shells**. Within a given shell, an electron holds a definite, fixed amount of energy — which is why these shells are also called **energy levels**. The shells are labelled, from the nucleus outward, as **K, L, M, N, ...**, corresponding to the numbers **n = 1, 2, 3, 4, ...**.

- Electrons can occupy only these permitted shells — never the space in between them.
- While an electron stays within one fixed shell, it does **not** lose energy, no matter how long it keeps circling.
- The K-shell (n = 1), closest to the nucleus, has the **least** energy of all the shells.
- Energy increases as you move outward: an electron in the L-shell (n = 2) has more energy than one in the K-shell, and so on, further out, further up.

- An electron can jump to another shell only by absorbing or releasing a fixed, exact packet of energy — equal to the difference between the two shells' energies.
- Each shell can hold only a fixed maximum number of electrons (you'll see the exact rule in section 8.7).

Bohr's key move was to simply *postulate* that in one of these stationary states, an electron's energy stays constant even while it keeps moving around the nucleus — sidestepping the classical expectation that a circling charge must always radiate energy away. It wasn't a proof from first principles; it was a bold, testable assumption that happened to match a mountain of experimental evidence about how atoms absorb and emit light. That combination — an audacious postulate, backed by hard data — is what made Bohr's model such a major leap forward.

Everyday Connection: Diwali Colours, Explained at Last

Remember the fireworks from the Opening Wonder? Here's the mechanism. Heat a sodium compound (as in a firecracker, or even ordinary salt held in a flame) and its electrons absorb energy, jumping briefly to a higher shell. They don't stay there — within a fraction of a second they fall back down to a lower shell, and in doing so, release that exact same fixed packet of energy as a burst of light of one particular colour. For sodium, that colour is a distinctive golden-yellow; for copper, blue-green; for strontium, red; for barium, green. Every element's electrons are only allowed to jump between its own specific set of shells, which is why each element burns with its own unmistakable colour signature — and why fireworks manufacturers choose their metal compounds by exactly this chemistry, not by mixing in paint.

Everyday Connection: Shells Like Metro Stations, Not a Highway

A Delhi Metro or Mumbai Metro train stops only at fixed, named stations — it cannot let you off halfway between two stations, no matter how much you'd like it to. Bohr's shells work the same way: an electron can exist in the K-shell or the L-shell, with a clean, definite jump between them, but it is never found drifting in the gap between two shells. Just as you 'jump' from one metro platform to another by boarding a train (an event, not a gradual slide), an electron jumps between shells by absorbing or emitting one packet of energy at a time.

Meet a Scientist: Niels Bohr (1885–1962)

Niels Bohr was a professor of physics at Copenhagen University, Denmark. He was troubled by the fact that older atomic models could not explain why electrons stay in motion around the nucleus without eventually collapsing into it. His explanation of atomic structure — built on fixed energy levels — brought far greater clarity to the problem and earned him the **1922 Nobel Prize** for his work on atomic structure.

Thread of Curiosity: Why K, L, M, N... and Not A, B, C, D?

The naming traces back to early X-ray experiments by physicist **Charles Barkla**, who labelled the very first X-ray line he observed as the "K" line. He deliberately didn't start from "A" — he wanted to leave room in the alphabet in case a series were later discovered even closer to the source than the K series, though none ever were. Bohr simply borrowed the same K, L, M, N naming for his atomic shells. Characteristic X-rays of exactly this kind are still put to work today — in hospital X-ray and CT machines across India, in airport and dental X-ray scanners, and in

materials-testing labs that check welds and castings without cutting them open.

Later still, even Bohr's model was found to have limitations — but that story, involving the quantum mechanical model, belongs to higher grades. For now, notice the pattern across this whole section: Thomson's model explained the electron but not the nucleus; Rutherford's model explained the nucleus but not stability; Bohr's model explained stability using fixed shells. **Each model was replaced not because it was foolish, but because it was tested against new evidence and found incomplete** — which is exactly how good science is supposed to work.

8.3 What Components Contribute to the Mass of an Atom?

Rutherford's model placed almost all of an atom's mass in its nucleus — the electrons revolving around it are so light that their mass can safely be ignored in most calculations. But early in the 20th century, something puzzling turned up. A hydrogen atom has just one proton. A helium atom has two protons — exactly double. Yet the mass of a helium atom is roughly **four times** that of a hydrogen atom, not two. If protons were the only thing contributing mass, the numbers simply didn't add up. Was there something else inside the nucleus, adding mass without adding any charge?

8.3.1 Discovery of the Neutron

In 1932, **James Chadwick** — a student of Rutherford's — solved the puzzle. He discovered a new subatomic particle with a mass nearly equal to that of a proton, but carrying **no electrical charge at all**. This neutral particle was named the **neutron**, symbol **n**. Neutrons are found in the nucleus of every atom except ordinary hydrogen. With the neutron in hand, the mass mismatch made sense at once: an atom's mass comes mainly from its protons *and* neutrons, packed tightly together in the nucleus — which is exactly why atoms are consistently heavier than just their total number of protons would suggest.

Subatomic particle	Symbol	Relative charge
Electron	e^-	−1
Proton	p^+	+1
Neutron	n^0	0

Meet a Scientist: James Chadwick (1891–1974)

Working under Rutherford at the famous Cavendish Laboratory, University of Cambridge, James Chadwick solved this key puzzle in 1932 by discovering the neutron. The breakthrough explained atomic mass fully for the first time and earned him the **1935 Nobel Prize in Physics**. The neutron immediately transformed research — because it carries no charge, it can slip past the electric repulsion that would otherwise block it from reaching a nucleus, opening the door to artificial radioactive elements, nuclear fission, and everything that followed.

Thread of Curiosity: Why Doesn't the Nucleus Blow Itself Apart?

Every proton in a nucleus carries the same positive charge, and like charges repel — so how do dozens of protons sit squeezed together in a space smaller than a trillionth of a metre without flying apart? Neutrons help in two ways: being uncharged, they physically separate protons from one another (reducing the repulsion), and they also add to the short-range **nuclear force** that binds all nucleons tightly together. This is why heavier atoms need proportionally *more* neutrons than protons: lighter atoms like carbon (6 protons, 6 neutrons) and oxygen (8 and 8) keep a roughly 1:1 ratio, but iron needs 26 protons to 30 neutrons, and by the time you reach uranium, the ratio has swung to 92 protons against 146 neutrons.

Everyday Connection: BARC, Right Here in Mumbai

The **Bhabha Atomic Research Centre (BARC)** in Mumbai runs advanced neutron-scattering experiments using research reactors such as **Dhruva**, firing beams of neutrons at materials to see how they respond. This work has revealed key insights into superconductors, battery electrode materials, and drug molecules — quietly supporting better medicines, longer-lasting batteries (including the kind charging your phone and, increasingly, electric two-wheelers on Indian roads), and stronger industrial alloys, all developed right here in India.

By 1869, scientists knew of about 69 naturally occurring elements. Today we know of **118** — some found in nature, some created artificially in laboratories, with the search for still more continuing. With so many elements to keep track of, chemists needed a compact, universal way to refer to each one — which is exactly the problem the next section solves.

8.4 Symbols of Elements

John Dalton realised that chemistry needed a standard, compact way to represent elements and compounds. In 1803, he introduced the first pictorial symbols for known elements — small drawn shapes, one per element. In 1813, the Swedish chemist **Berzelius** suggested something far more practical: deriving symbols from elements' **Latin names**, giving us the alphabetic chemical symbols still in use today. This system is now maintained by the **International Union of Pure and Applied Chemistry (IUPAC)**, which formally approves the name and symbol of every known element.

A few rules IUPAC symbols always follow:

- Many symbols are simply the first letter, or first two letters, of the element's name.
- The first letter is always capital; the second letter (if any) is always lower-case — hydrogen is **H**, aluminium is **Al** (never AL), cobalt is **Co** (never CO).
- Some symbols use the first letter plus a different letter from later in the name — chlorine is **Cl**, zinc is **Zn**.
- Some symbols come from Latin, Greek, or German names rather than English: iron is **Fe** (Latin *ferrum*), mercury is **Hg** (Greek *hydrargyros*), tungsten is **W** (German *wolfram*).

Element	Symbol	Element	Symbol
Aluminium	Al	Iron (Ferrum)	Fe
Carbon	C	Nitrogen	N

Element	Symbol	Element	Symbol
Chlorine	Cl	Oxygen	O
Copper (Cuprum)	Cu	Potassium (Kalium)	K
Gold (Aurum)	Au	Silicon	Si
Hydrogen	H	Silver (Argentum)	Ag
Iodine	I	Sodium (Natrium)	Na
Lead (Plumbum)	Pb	Sulfur	S
Magnesium	Mg	Zinc	Zn
Calcium	Ca	Uranium	U

Everyday Connection: Reading Your Salt Packet and Fertiliser Bag

Next time you're in the kitchen, check a packet of **iodised salt** — the "I" added to prevent iodine-deficiency disorders is the same IUPAC symbol you've just learned, for the element iodine. Walk through a fertiliser shop or an agricultural supply store and you'll see bags labelled **N-P-K**, standing for nitrogen, phosphorus, and potassium — the three elements every crop needs most, and the same three symbols from Table 8.2. Even the calcium-and-iron-fortified milk and supplement adverts that run on Indian television during cricket matches are, whether they say so explicitly or not, talking about **Ca** and **Fe** — because a shared, unambiguous symbol lets a doctor in Chennai, a farmer in Punjab, and a chemist in Berlin all know exactly which element is meant, with zero translation needed.

Thread of Curiosity: The Old Names Hiding Inside New Symbols

Iron's symbol, **Fe**, comes from the Latin *ferrum* — the same root that gives railways their "ferrous" tracks. Mercury's symbol, **Hg**, comes from the Greek *hydrargyros*, literally "liquid silver," a fitting description for the only metal that is liquid at room temperature (mercury thermometers, once common in Indian homes and clinics, have now been largely phased out under the international Minamata Convention because of mercury's toxicity — a nice example of chemistry knowledge shaping public health policy). Tungsten's symbol, **W**, comes from the German *wolfram*, and gave old incandescent bulb filaments their glow for over a century, before LED bulbs made them mostly obsolete in Indian homes.

8.5 Atomic Number

You've learnt that atoms of the same element are all alike, yet different from the atoms of any other element — and that this difference lies in the number of protons and electrons they contain. The number of protons in the nucleus of an atom of an element is called its **atomic number**, given the symbol **Z**. This single number determines the identity of an element and governs its chemical behaviour.

Since an atom as a whole is neutral, the number of protons in it must equal the number of electrons orbiting the nucleus. Hydrogen has 1 proton and 1 electron, so its atomic number is **1**. Helium has 2 protons and 2 electrons, so its atomic number is **2**. No two

different elements ever share the same atomic number — Z uniquely identifies the element.

8.6 Mass Number

Recall that a helium atom has only two protons, yet its mass is about four times that of a single proton — a puzzle that section 8.3 resolved with the discovery of the neutron. The total number of protons and neutrons in an atom's nucleus is called its **mass number**, symbol **A**. Protons and neutrons together are called **nucleons**.

> **Definition**
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> **Mass number (A) = number of protons + number of neutrons**

Since a neutron's mass is roughly equal to a proton's, helium's mass is fully accounted for by 2 protons plus 2 neutrons — giving A = 4, matching experiment exactly.

Element	Protons (p^+)	Neutrons (n^0)	Mass number (A)
Hydrogen	1	0	1
Helium	2	2	4
Lithium	3	4	7

An atom is written in standard notation with its mass number as a left superscript and its atomic number as a left subscript, before the element's symbol. For carbon (symbol C, atomic number 6, mass number 12), this is written $^{12}_{6}\mathrm{C}$. Electrons, in comparison, have negligible mass and are ignored in these calculations.

> **Worked Example — Redeveloped: Your Aadhaar Number vs Your Weight**
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> **Original book version:** The standard notation of carbon is written with atomic number 6 and mass number 12, as $^{12}_{6}\mathrm{C}$.
>
> **Everyday Version:** Think of the **atomic number (Z)** as an element's Aadhaar number: fixed, permanent, and uniquely tied to its identity — change it, and you literally become a different element, the way you'd become a different person if your Aadhaar number changed. The **mass number (A)**, on the other hand, behaves more like your body weight: it can vary from one atom of an element to another (as you'll see with isotopes in section 8.9) without changing who — or what element — you fundamentally are.
>
> **Try it:** Phosphorus, a key ingredient in the DAP fertiliser bags stacked outside agricultural supply shops across rural India, has atomic number 15 and mass number 31. Using Z = number of protons = number of electrons, and A = protons + neutrons, find the number of protons, neutrons, and electrons in a phosphorus atom.
>
> **Working it out:** Protons = electrons = Z = **15**. Neutrons = A − Z = 31 − 15 = **16**.

8.7 How Are Electrons Distributed in Different Energy Levels?

Physicists Niels Bohr and Walter Bury proposed a small set of rules governing how electrons fill an atom's shells:

- The maximum number of electrons a shell can hold is given by **$2n^2$**, where n is the shell number: K-shell (n = 1) holds $2 \times 1^2 = \mathbf{2}$ electrons; L-shell (n = 2) holds $2 \times 2^2 = \mathbf{8}$; M-shell (n = 3) holds $2 \times 3^2 = \mathbf{18}$.
- The outermost shell of any atom can never hold more than **8** electrons (except the very first shell, which maxes out at 2).
- Electrons fill shells in strict order, starting closest to the nucleus and working outward — K, then L, then M, then N — and a shell must be completely filled before the next one begins to fill.

Hydrogen (atomic number 1) has its single electron sitting in the K-shell. Helium (atomic number 2) has both its electrons in the K-shell, completing it. From there, each additional electron — one per increase in atomic number — goes into the next available shell, building up the full range of elements one atom at a time. This electron arrangement across shells is called the **electronic configuration** of an atom.

> **Everyday Connection: Filling Up Like the Lower Tier of a Cricket Stadium**
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> Picture Wankhede Stadium filling up before an IPL final: ushers direct the crowd to fill the lower tier completely before anyone is allowed into the upper tier. Electrons behave the same way — the K-shell (capacity 2) fills up entirely before a single electron is allowed into the L-shell (capacity 8), and the L-shell fills up entirely before the M-shell begins. It's an orderly, floor-by-floor filling rule, not a free-for-all.

Table 8.4 lists the electronic configuration of the first eighteen elements — the ones you'll use constantly through the rest of this course.

Element	Symbol	Z	p^+	n^0	e^-	K, L, M
Hydrogen	H	1	1	0	1	1
Helium	He	2	2	2	2	2
Lithium	Li	3	3	4	3	2, 1
Beryllium	Be	4	4	5	4	2, 2
Boron	B	5	5	6	5	2, 3
Carbon	C	6	6	6	6	2, 4
Nitrogen	N	7	7	7	7	2, 5
Oxygen	O	8	8	8	8	2, 6
Fluorine	F	9	9	10	9	2, 7
Neon	Ne	10	10	10	10	2, 8
Sodium	Na	11	11	12	11	2, 8, 1
Magnesium	Mg	12	12	12	12	2, 8, 2
Aluminium	Al	13	13	14	13	2, 8, 3

Element	Symbol	Z	p^+	n^0	e^-	K, L, M
Silicon	Si	14	14	14	14	2, 8, 4
Phosphorus	P	15	15	16	15	2, 8, 5
Sulfur	S	16	16	16	16	2, 8, 6
Chlorine	Cl	17	17	18	17	2, 8, 7
Argon	Ar	18	18	22	18	2, 8, 8

Activity — Redeveloped: Draw the Atoms Inside Your Everyday World

Original book version: Build up two-dimensional atomic structures for various elements by adding one electron to the appropriate shell each time the atomic number increases by 1.

Everyday Version: Using Table 8.4, draw Bohr shell diagrams (nucleus at the centre, shells as concentric circles with dots for electrons) for four elements you interact with daily: **silicon** (the element at the heart of every smartphone and laptop processor chip), **sodium** and **chlorine** (the two halves of the salt on your dining table), and **oxygen** (the gas keeping you alive right now). For each, label the number of protons, neutrons, and the shell-wise electron distribution.

Bonus Question: Sodium (2, 8, 1) and chlorine (2, 8, 7) look almost like mirror images of each other in their outermost shells. Keep that observation in mind — section 8.8 will show you exactly why it makes them such perfect chemical partners in ordinary table salt.

8.8 Combining Capacity of an Atom: Valency

Atoms of the same or different elements combine to form molecules. The number of hydrogen or chlorine atoms with which one atom of an element can combine to form a compound is called its **combining capacity** — expressed relative to hydrogen and chlorine because both have a combining capacity of exactly one. In H_2O (water), one oxygen atom combines with two hydrogen atoms, so oxygen's combining capacity is **2**.

The outermost, electron-containing shell of an atom is called its **valence shell**, and the electrons in it are its **valence electrons**. If that outermost shell holds exactly 8 electrons, it is called an **octet**. Atoms with a complete octet (or, for helium, 2 electrons in its only shell) are largely unreactive and stable. Atoms with an *incomplete* valence shell are typically more reactive — they lose, gain, or share electrons in order to complete their octet. The number of electrons an atom gains, loses, or shares to achieve this is called its **valency**.

Generally, an element with fewer than four valence electrons tends to **lose** electrons to reach a stable octet; an element with more than four tends to **gain** electrons instead. Sodium's electronic configuration is 2, 8, 1 — one electron away from an empty outer shell, so it loses that single electron, giving it a **valency of 1**. Oxygen's configuration is 2, 6 — it gains two electrons to complete its octet, giving a **valency of 2**. Carbon's configuration is 2, 4 — exactly halfway, so instead of losing or gaining, carbon typically **shares** four electrons with other atoms, giving it a **valency of 4**.

Everyday Connection: The LPG Cylinder in Every Indian Kitchen

The cooking gas in an LPG cylinder is mostly **methane and propane-type hydrocarbons** — built from carbon atoms (valency 4) each bonded to hydrogen atoms (valency 1). A single carbon atom in methane (CH_4) shares all four of its valence electrons with four separate hydrogen atoms, one electron pair per bond, filling its octet completely. The same valency rule that explains why oxygen (valency 2) needs two hydrogens to make H_2O also explains exactly how many hydrogen atoms carbon needs to satisfy its own combining capacity — the chemistry quietly at work every time the stove lights.

Worked Example — Redeveloped: Reading Valency Off a Fertiliser and a Tofu-Setting Salt

Original book version: In NH_3 (ammonia) and $MgCl_2$ (magnesium chloride), what are the combining capacities of nitrogen and magnesium?

Everyday Version: Ammonia (NH_3) is the starting point for most nitrogen fertilisers spread across Indian farmland, and magnesium chloride (sold as "nigari") is used to set soft tofu. In NH_3, one nitrogen atom combines with three hydrogen atoms, so nitrogen's valency is **3**. In $MgCl_2$, one magnesium atom combines with two chlorine atoms, so magnesium's valency is **2** — which checks out against its electronic configuration, 2, 8, 2: two electrons away from an empty outer shell, so it loses exactly two.

You may wonder: what about atoms that already have a full octet — do they still try to lose or gain electrons? Elements like neon and argon (both already at 8 valence electrons, or helium at 2) have no drive to react further, which is exactly why this whole family of elements is called the **noble gases** — chemically aloof, almost never forming compounds under ordinary conditions.

So far, every atom of a given element you've seen has had the same number of protons and the same number of neutrons. Is that always true? Scientists discovered it is not — and that discovery opens up the final, and arguably strangest, part of this chapter's story.

8.9 A Deeper Look into Atomic Structure

8.9.1 Isotopes

Dalton assumed every atom of a given element was identical, with exactly the same mass. Scientists later discovered this isn't quite right: atoms of the same element — same number of protons, same atomic number (Z) — can have **different** numbers of neutrons, and therefore different mass numbers (A = protons + neutrons). These "twin atoms," sharing an atomic number but differing in mass number, are called **isotopes**.

Naturally occurring hydrogen is a mixture of three isotopes: $^{1}_{1}H$ (**protium**, about 99.98% of natural hydrogen), $^{2}_{1}H$ (**deuterium**, about 0.015%), and $^{3}_{1}H$ (**tritium**, present only in traces). All three have exactly one proton (and, since atoms are neutral, exactly one electron); deuterium additionally carries one neutron, and tritium carries two.

Because isotopes of the same element always have the same number of electrons — and therefore the same electronic configuration — their **chemical properties are essentially identical**. Chemical behaviour depends mainly on valence electrons, after

all, not on the neutron count sitting quietly in the nucleus. What *does* differ between isotopes are their **physical properties**, such as boiling and melting points. Carbon, similarly, has three well-known isotopes — $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$ — each with six protons and six electrons, differing only in neutron count. $^{12}_{6}C$ is by far the most abundant in nature.

Everyday Connection: Dating the Indus Valley with C-14

The radioactive isotope $^{14}_{6}C$ decays at a steady, known rate. When archaeologists at sites like **Dholavira** or **Rakhigarhi** — major Indus Valley Civilisation excavations in India — recover ancient wooden tools, cloth fragments, or bone, they measure how much $^{14}_{6}C$ remains compared to ordinary $^{12}_{6}C$ to estimate the artefact's age, often to within a few centuries even for objects thousands of years old. The Archaeological Survey of India relies on exactly this technique — radiocarbon dating — to help place India's ancient past on a firm timeline.

Bridging Science and Society: Isotopes at Work

- $^{235}_{92}U$ (uranium-235) fuels nuclear reactors, generating electricity at power plants such as the **Kudankulam Nuclear Power Plant** in Tamil Nadu, India's largest.
- $^{60}_{27}Co$ (cobalt-60), a radioactive isotope, powers radiation therapy machines used in cancer treatment at hospitals such as **Tata Memorial Hospital**, Mumbai.
- $^{131}_{53}I$ (iodine-131) is used to treat goitre and thyroid cancer.
- $^{14}_{6}C$ (carbon-14) is used in archaeology and geology to date ancient fossils and artefacts, exactly as described above.

Ready to Go Beyond: Why Chemists Invented a Whole New Unit for Weight

Atoms are far too tiny to be weighed in kilograms or grams the way you'd weigh vegetables at a sabzi mandi. Just as it's more sensible to weigh a single grain of wheat in milligrams than kilograms, scientists measure atomic mass in a special unit called the **unified atomic mass unit (u)** — historically called the atomic mass unit, or amu. One u is defined as exactly one-twelfth the mass of a single $^{12}_{6}C$ atom, making carbon-12 the reference point for every other atom's mass.

A. Average atomic mass

Chlorine occurs in nature as a mix of two isotopes: one with mass 35 u, the other with mass 37 u. So should we call the mass of "a chlorine atom" 35 u, 36 u, or 37 u? A simple, unweighted average of the two isotope masses gives (35 + 37) ÷ 2 = **36 u** — but this silently assumes both isotopes occur equally often in nature, which they don't.

In reality, $^{35}_{17}Cl$ makes up about **75%** of natural chlorine, while $^{37}_{17}Cl$ makes up the remaining **25%**. Accounting for this properly requires a **weighted average atomic mass** — multiplying each isotope's mass by its fractional abundance, then adding the results.

Worked Example — Redeveloped: Weighted Average, Like Your Report Card

Original book version: Calculate chlorine's average atomic mass given $^{35}_{17}Cl$ and $^{37}_{17}Cl$ occurring in a 3:1 ratio (75% and 25%).

Everyday Version: You've almost certainly calculated a weighted average before,

even if no one called it that — it's exactly how your overall percentage is computed when different subjects carry different credit weightage, or how a cricket player's career batting average weighs a 150-run innings more heavily than a 12-run one. Chlorine's atomic mass works the same way: a more abundant isotope pulls the average closer to its own mass.

Working it out:

Average atomic mass = (35 × 75⁄100) + (37 × 25⁄100) = 26.25 + 9.25 = **35.5 u**

This does **not** mean any single chlorine atom has a fractional mass of 35.5 u — no atom can have "half" a neutron. It means that out of, say, one million chlorine atoms in nature, roughly **7.5 lakh** would be $^{35}_{17}Cl$ and roughly **2.5 lakh** would be $^{37}_{17}Cl$, and the *collective* average mass per atom works out to 35.5 u — exactly the number printed for chlorine on every periodic table.

Meet a Scientist: Homi Jehangir Bhabha (1909–1966)

Homi J. Bhabha was an Indian physicist known as the **father of the Indian nuclear programme**. He made pioneering contributions to the development of atomic energy in India, founding two institutions still central to Indian science today: the **Tata Institute of Fundamental Research (TIFR)** and what became the **Bhabha Atomic Research Centre (BARC)** — both aimed squarely at the peaceful use of atomic energy to generate electricity, support agriculture, and advance medical treatment across the country.

8.9.2 Isobars

Isotopes share an atomic number but differ in mass number. What about atoms that share a mass number but have *different* atomic numbers? Consider calcium (atomic number 20), potassium (atomic number 19), and argon (atomic number 18): each has a different number of protons, yet **each has a mass number of 40**. The total number of nucleons is identical across all three, even though they are three entirely different elements with entirely different chemistry. Atoms of different elements that share the same mass number but differ in atomic number are called **isobars**.

Thread of Curiosity: The Same Word Turns Up on the Weather Map

If you've studied weather maps in geography class, you may already know the word "isobar" in a completely different sense: a line on a weather map connecting points of **equal atmospheric pressure**. That's not a coincidence — both meanings come from the Greek *isos* ("equal") plus *baros* ("weight" or "pressure"). A meteorological isobar marks equal pressure; an atomic isobar marks equal mass (a kind of "weight"). Same Greek roots, two very different sciences, one elegant shared idea: equal in one respect, different in every other.

As this journey into atomic structure draws to a close for now, it's worth being honest about where it actually stands: it isn't finished. Later research showed that even Bohr's model isn't entirely correct — electrons don't really travel along neat, fixed circular tracks. Today, physicists describe electrons as existing in **electron clouds** around the nucleus: regions where an electron is *likely* to be found, rather than an exact path it follows. You'll meet this quantum mechanical picture properly in higher grades. Modern instruments such as **Scanning Tunnelling Microscopes (STMs)** and **Transmission Electron Microscopes (TEMs)** — used in nanotechnology research at institutions like the IITs and IISc — can now image individual atoms directly, turning what was once pure inference into something you can, almost, see with your own eyes.

Chapter Summary

Concept	Core idea	Everyday example
Ancient atomic ideas	Kanada's *parmanu* and the Greek *atomos* proposed indivisible particles through reasoning alone	Zooming into a photo until you hit solid pixels
Dalton's atomic theory (1808)	Matter is made of indivisible atoms, based on experimental evidence	Element symbols on a salt packet
Thomson's model	Electrons embedded in a sphere of positive charge ("plum pudding")	A watermelon: red pulp positive, seeds negative
Gold foil experiment	Alpha particles mostly pass through gold foil, but a few scatter sharply	A metro station's X-ray baggage scanner
Rutherford's model	Dense, positively charged nucleus at the centre; atom is mostly empty space	A pepper grain at the centre of a cricket ground
Bohr's model	Electrons occupy fixed energy-level shells (K, L, M, N…) without losing energy	Metro trains stopping only at fixed stations
Neutron (Chadwick, 1932)	Neutral particle in the nucleus, explaining atomic mass fully	Why helium is 4× hydrogen's mass, not 2×
Atomic number (Z)	Number of protons; uniquely identifies an element	An element's "Aadhaar number"
Mass number (A)	Total nucleons: protons + neutrons	An element's "body weight" — can vary
Electron distribution ($2n^2$ rule)	Shells fill in order, K before L before M, with fixed maximum capacities	Filling a stadium's lower tier before the upper tier
Valency	Electrons lost, gained, or shared to complete an octet	Carbon's 4 bonds in LPG cooking gas
Isotopes	Same atomic number, different mass number (different neutrons)	Carbon-14 dating Indus Valley artefacts
Average atomic mass	Weighted average of isotope masses by natural abundance	Your overall percentage across weighted subjects
Isobars	Different elements, same mass number	Calcium-40, potassium-40, and argon-40

Revise, Reflect, Refine — Exercises

Basic Recall

1. Differentiate between isotopes and isobars, giving one real example of each (you may use the chlorine isotopes or the calcium/potassium/argon isobars discussed in this chapter).

2. Rutherford's model successfully explained the gold foil experiment but failed to explain one crucial thing about atoms. What was it, and how did Bohr's model resolve it?
3. State the two rules (from Bohr and Bury) that govern the maximum number of electrons a shell can hold, and the maximum allowed in the outermost shell.

Apply & Think

4. **Numeric:** Silver occurs in nature as two isotopes: $^{107}_{47}Ag$ with an abundance of 51.8%, and $^{109}_{47}Ag$ with an abundance of 48.2% — relevant the next time you see silver jewellery being weighed and priced at a shop ahead of Diwali or a wedding. Calculate silver's weighted average atomic mass, showing your working as in the chlorine worked example.
5. **Numeric:** An atom of magnesium (essential for muscle contraction, and a mineral often mentioned in supplement advertisements) has mass number 24 and atomic number 12. Find (i) the number of protons, (ii) the number of neutrons, (iii) the number of electrons, and (iv) write out its electronic configuration across shells.
6. A relative forwards you a message claiming: *"Standing near a mobile phone tower breaks apart the atoms in your body and causes cancer."* Using the mechanism-based questioning approach (ask: what is the actual physical process being claimed? does it have the energy required to actually do this?), evaluate whether ordinary radio-frequency signals from mobile towers carry enough energy to knock electrons out of atoms (a process called ionisation) the way an X-ray or a radioactive isotope like cobalt-60 can. Write a short, evidence-based reply you could send back.

Creative Design Challenges

7. **The Atom ID Card:** Design an "Aadhaar-style" identity card for any element of your choice, displaying its atomic number, mass number, number of protons/neutrons/electrons, full electronic configuration, and valency — with a short justification for each field, the way an ID card justifies each piece of information it carries.
8. **The Kitchen Bohr Model:** Using household items (a plate for the nucleus, and dried peas, beads, or seeds arranged in circles for electrons), physically build a Bohr model of an element with at least three shells (for example, sodium, chlorine, or argon). Photograph or sketch it, labelling every shell with its electron count and energy ranking.
9. **Courtroom of the Atomic Models:** Write a short courtroom-style script in which Dalton, Thomson, Rutherford, and Bohr each defend their own atomic model with the evidence available to them at the time, while a "judge" (a later scientist, or you) cross-examines each with the very evidence that eventually overturned it.
10. **The Grandparent WhatsApp Explainer:** Write a short WhatsApp-style chat thread (5–8 messages) in which you explain isotopes to a grandparent who has just heard the word "radioactive" on the news and is worried about carbon dating or nuclear power — using plain language, at least one everyday analogy from this chapter, and no unnecessary jargon.

🚀 Journey Beyond — Going Deeper

Challenge A: India's Atomic Footprint

Research one Indian institution or programme built on the atomic-structure ideas in this chapter — the Kudankulam or Tarapur nuclear power stations, BARC's Dhruva reactor, Tata Memorial Hospital's use of cobalt-60 in cancer therapy, or the Archaeological Survey of India's use of carbon-14 dating. Write a short report (200–250 words) on what the institution does, which subatomic particle or isotope is central to its work, and why that particular isotope was chosen over others.

Challenge B: The Rice-Grain Estimate

Section 8.2.2's "Ready to Go Beyond" box calculated that roughly a million atoms, stacked edge to edge, span the thickness of a sheet of paper (or a human hair). Extend that style of estimation: research the approximate diameter of a carbon or hydrogen atom, and the approximate dimensions of a single grain of cooked rice, then estimate — showing every assumption — roughly how many atoms make up one grain of rice. (Hint: you will need to estimate the rice grain's volume, and you may assume its density is close to that of water for a rough estimate.)

Challenge C: Simulate It Yourself

Explore the PhET simulations *Rutherford Scattering* and *Isotopes and Atomic Mass* (search for them at phet.colorado.edu). In the scattering simulation, try firing alpha particles at different model atoms (plum pudding vs nuclear) and note how the scattering pattern changes. In the isotopes simulation, adjust the number of neutrons in a nucleus and observe how the average atomic mass shifts as you mix isotopes in different proportions — connecting directly back to the chlorine and silver weighted-average calculations in this chapter. Write down two observations that surprised you.

The Quest Continues... Is it possible to completely understand everything that happens inside an atom? Every model in this chapter was our best answer for its time — and every one of them, eventually, was improved. Perhaps yours will be too.